180,939 (87) 3 copies w/o claims

PATENTS-US--A7180939

4-13-88

W-7405-ENG-36

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FIBER OPTIC LASER ROD

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FIBER OPTIC LASER ROD

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BACKGROUND OF THE INVENTION

This invention relates to laser rods and, more particularly, to plastic dye-doped laser rods. This invention is the result of a contract with the Department of Energy (Contract No. W-7405-ENG-36).

There are substantial applications where a simple, inexpensive, storable, and compact laser system is desired. In many such applications the laser rod may be damaged or destroyed after a single lasing action such that conventional glass or crystal laser rods or flowing liquid dye solvent lasers become too expensive or complex. Dye-doped plastic laser rods offer the potential for low cost laser rods. Organic polymers, e.g., plastics, such as acrylics, have been studied for use in laser application. By way of example, U.S. Patent No. 4,139,342, issued February 13, 1979, to Sheldrake et al. discloses a process for doping laser dyes into plastic hosts.

There are, however, substantial problems with obtaining high power laser outputs from plastic rods. In the first instance, plastics generally have low optical quality when compared to inorganic crystal and glass laser hosts. In the second place, the physical characteristics of plastics lead to serious consequences. The coefficient of thermal expansion for plastics is generally an order of magnitude greater than for inorganic glasses and crystal hosts. The inverse is true for the thermal conductivity of plastics. The refractive index of plastics changes with temperature in a function closely related to the coefficient of thermal expansion. Accordingly, the optical thermal stability of plastic dye-doped laser rods is about two orders of magnitude poorer than inorganic glasses and crystal hosts.

Plastic dye-doped laser rods also have mechanical stability concerns. Increased physical support must be provided for use under stress, vibration, or acceleration loads. Large thermal gradients across the plastic rod can cause rod bending which will misalign the optical cavity. Plastics are subject to photochemical damage and laser dyes can undergo photochemical damage or bleaching in the rod. Plastics are, however, more resistant to mechanical and thermal shock and impact damage.

These problems and others are addressed by the present invention wherein a laser rod having a plurality of individual fiber optic dye-doped plastic fibers is provided.

It is an object of the present invention to provide a plastic laser rod.

It is another object of the present invention to provide a laser rod having fiber optic lasers synchronized by evanescent wave coupling.

One other object of the present invention is to provide a plastic laser rod which can be inexpensively fabricated.

Additional objects, advantages and novel features of the invention will be set forth in part in the description which follows, and in part will become apparent to those skilled in the art upon examination of the following or may be learned by practice of the invention. The objects and advantages of the invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

SUMMARY OF THE INVENTION

To achieve the foregoing and other objects, and in accordance with the purposes of the present invention, as embodied and broadly described herein, the apparatus of this invention may comprise a laser rod having a plurality of optical fibers each having a dye-doped core for lasing. Each laser core is spaced from at least one adjacent core a coupling distance effective for evanescent wave coupling.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and form a part of the specification, illustrate the embodiment of the present invention and, together with the description, serve to explain the principles of the invention. In the drawings:

FIGURE 1 is a cross section of a clad dye-doped plastic optical fiber according to one embodiment of the present invention.

FIGURE 2 is a cross-sectional view of a laser rod according to the present invention.

DETAILED DESCRIPTION

A laser rod is formed according to the present invention from a bonded, fiber optic bundle of plastic fiber optics with dye-doped cores. Each optical fiber forms an individual laser. The small diameter of the fiber minimizes thermal gradients and optical distortion in the fiber to enable plastics of relatively poor optical quality to be used.

As shown in Figure 1, each fiber optic laser 10 would be formed from a dye-doped plastic fiber core 12 having a surrounding clear, undoped clad 14. Plastic cladding 14 has a relatively lower refractive index than plastic fiber core 12 in order to substantially optically insulate adjacent fiber optic lasers, except as hereinafter discussed. Plastic clad plastic fiber optics are conventional. As herein disclosed, plastic fiber core 12 may preferably be an acrylic, such as polymethyl methacrylate (PMMA). PMMA can have adequate optical quality used with conventional dyes such as Coumarin, Rhodamin, and Kiton Red. A polymerizable solvent, such as 5-10% of a hydroxylated acrylic, e.g., hydroxyethyl methacrylate, is used to incorporate the selected dye into the PMMA.

Cladding 14 is selected to pass pumping light to plastic core 12 and, with the slightly higher index of refraction mentioned above, to confine lasing light within core 12. Cladding 14 is also selected to have a softening temperature less than the softening temperature of plastic core 12 to enable the laser rod depicted in Figure 2 to be formed, as hereinafter discussed. Only a small change is needed in the index of refraction, i.e., parts per hundred, to provide a fiber optic isolation.

Cladding 14 might be formed from a different plastic than plastic core 12, where cladding 14 is not cross-linked. The noncross-linked cladding 14 would be expected to have a lower softening temperature and a sufficient change in the index of refraction to form the fiber optic. Thus, if cross-linked PMMA forms fiber 12, uncross-linked polystyrene may form the cladding 14.

Referring now to Figure 2, there is shown a cross-sectional view of laser rod 20 according to one embodiment of the present invention. Laser rod 20 is formed from a plurality of dye-doped plastic fiber cores 22 surrounded by interstitial material 24. Plastic cores 22 and interstitial material 24 have the same characteristics and may be formed from the same materials discussed above for plastic core 12 and clad 14 in fiber optic laser 10 (Figure 10), respectively. Interstitial material 24 has an optical quality sufficient to transmit pumping light to the interior of laser rod 20 while providing the desired optical isolation. Laser rod 20 may be formed from fiber optic lasers 10 (Figure 1) by hot pressing a plurality of fiber optic lasers 10 into a predetermined proximity. Cladding 14 (Figure 1) is sufficiently softened to fill the interstitial spaces while maintaining at least a selected separation d between adjacent plastic fibers 22 in the compressed fiber rod 20.

Individual dye-doped plastic cores 22 are substantially optically isolated from adjacent cores 22. If the isolation were complete, then relatively unsynchronized laser action would be expected from laser rod 20. However, when plastic cores 22 are placed in close proximity, evanescent wave coupling is expected across the internally reflective boundaries between core 22 and interstitial material 24 by the evanescent wave penetrating the small thickness d of material 24 between adjacent cores 22.

Evanescent wave coupling is a well-known quantum effect wherein coupling occurs across an otherwise internally reflecting boundary at surface separations less than about ten wavelengths of the light being reflected. The conventional dyes mentioned above have laser outputs from around 0.4 to 0.7 μm, so suitable core 22-to-core 22 spacings d may be expected in a range of about 0.4 to 7.0 μm. The evanescent wave coupling would occur along the entire length of adjacent plastic fiber cores 22 having a spacing d effective for evanescent wave coupling.

Evanescent wave coupling will tend to force the individual fibers to lase in a synchronized manner so that the entire fiber optic laser bundle (laser rod 20) acts as a substantially coherent light source. Further, by partitioning laser rod 20 into many small lasing regions, dye doped plastic cores 22 will permit relatively large refractive index gradients across laser rod 20 to exist without disturbing the synchronism of individual lasing fiber cores 22, where different optical wave modes can be accommodated.

Laser rod 20 is completed by forming laser cavity mirrors in contact with the cut and polished ends of plastic cores 22. Mirror surfaces may be individually formed or may be formed over the end surface of laser rod 20. It will be appreciated that individual cores 22 may effectively change their cavity length across the width of laser rod 20 under a temperature gradient. However, by appropriately choosing the diameter of plastic fiber 22 and the length of fibers 22 to accommodate multimode operation, evanescent wave coupling synchronization may force synchronization even with slightly different cavity lengths by forcing suitable different operating modes in the various cores 22.

It is expected that the diameter of plastic cores 22 can range from tens of microns to about 1.0 mm, with a preferred size of about 50-100 μm. A lower size limit is selected to prevent a single mode limitation within the core, i.e., to permit multiple modes to exist within the core so that evanescent wave coupling can force synchronization. An upper size limit is selected so that relatively small temperature gradients will exist across the fiber.

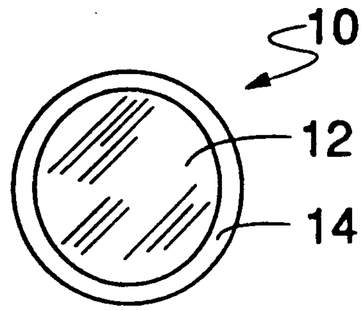
It will be appreciated that, while the above discussion has been directed to plastic clad plastic fiber cores, metal ion-doped glass fiber cores could also be formed in a laser rod in accordance with the present invention. Such a formation might be desirable if, for example, arcuate lasers can be fabricated from the fiber optics formed in the fiber optic bundle. Again, the requirements remain that the cladding material has a lower index of refraction than the fiber optic core material and that the cladding has a lower softening temperature.

The foregoing description of the preferred embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and obviously many modifications and variations are possible in light of the above teaching. The embodiment was chosen and described in order to best explain the principles of the invention and its practical application to thereby enable others skilled in the art to best utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims appended hereto.

ABSTRACT OF THE DISCLOSURE

A laser rod is formed from a plurality of optical fibers, each forming an individual laser. Synchronization of the individual fiber lasers is obtained by evanescent wave coupling between adjacent optical fiber cores. The fiber cores are dye-doped and spaced at a distance appropriate for evanescent wave coupling at the wavelength of the selected dye. An interstitial material having an index of refraction lower than that of the fiber core provides the optical isolation for effective lasing action while maintaining the cores at the appropriate coupling distance.

Fig.1



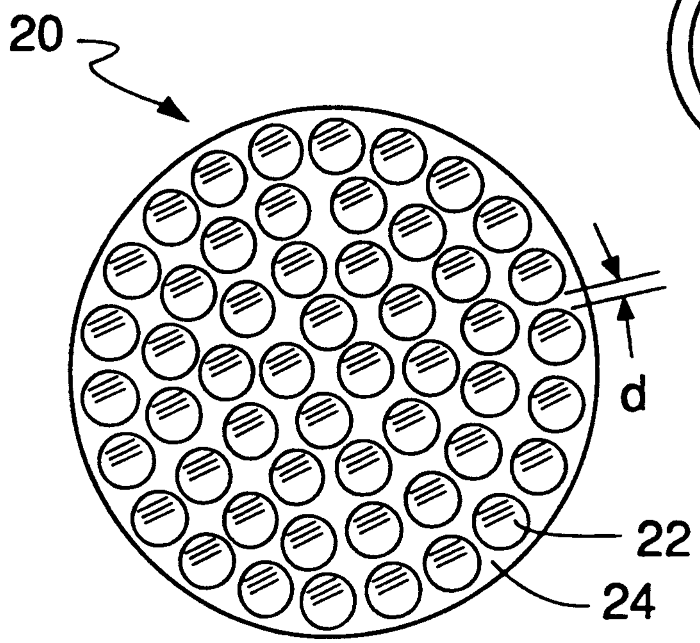


Fig.2